Effect of a beating process, as a means of reducing salt content in Chinese-style meatballs (kung-wan): A physico-chemical and textural study

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Two different meat-cutting methods were used to prepare kung-wans in an attempt to produce low-salt products while retaining the same, or improved, textural and physicochemical properties of the standard high-salt formulation. The level of salt and the processing method significantly affected color, cooking yield, texture and changes in the secondary structures of proteins. Improved salt levels resulted in firmer texture. At the same salt levels, compared with chopping, the beating method resulted in higher L⁎-values, improved cooking yields and changes in the β-sheet content of the proteins, which resulted in an improved product with better texture. Using the beating process, the kung-wans prepared with 1% and 2% salt had similar L⁎-values, cooking yield and texture, and were better than those prepared by chopping with 2% salt. Overall, the beating process enabled lowering of the salt content, making the kung-wans more hard, brittle and elastic.

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1. Introduction

In China, there are records of meatball products dating back to the 6th century in Qi Min Yao Shu. Currently, kung-wan is the most important product representing the original Chinese-style meatballs. As a result of its distinct processing method, the eating qualities of kung-wans differ from those of other emulsified meat products, by enhancing the hardness, brittleness and elasticity (Hsu & Chung, 1998; Hsu & Yu, 1999). Emulsion formation and stability of emulsified meats is markedly affected by salt content. The salt plays an important role in the solubilization of the myofibrillar proteins, as it is these proteins that determine the binding and textural characteristics of the product (Pietrasik & Li-Chan, 2002; Sikes, Tobin, & Tume, 2009). Salt also contributes to flavor (Matulis, McKeith, Sutherland, & Brewer, 1995; Ruusunen et al., 2005; Tobin, O’Sullivan, Hamill, & Kerry, 2013). Excessive dietary salt intake however can raise blood pressure, which is a major cause of cardiovascular disease (He & MacGregor, 2002; Sacks, Svetkey, & Vollmer, 2001). Reduction of salt in meat products has therefore become an important research field (Ma et al., 2012; Omana, Plastow, & Betti, 2011; Ventanasa, Puolanne, & Tuorila, 2010).

A novel beating machine (Fig. 1) has been designed for commercial use which simulates beating and blending meat with a stick, the traditional way the kung-wan was produced in Asian communities. Chopping is one of the basic procedures in the manufacture of minced meat products and some researchers have used a bowl cutter to produce kung-wan (Lin & Lin, 2004; Wu & Lin, 2011). Currently we do not have a thorough understanding of the underlying mechanisms that account for the desirable characteristics of hardness and elasticity of kung-wans made with these chopping or beating methods. The objective of the present study was to investigate the effect of salt content and the processing technique (beating or chopping) on the properties of raw batters and kung-wans, and to establish a procedure to obtain kung-wans of a desirable texture.

2. Material and method

2.1. Preparation of meatballs (kung-wan)

Meatballs (kung-wan) were prepared from pork leg meat (semitendinosus, biceps femoris, mesoglutaeus) using a number of different formulations and processing methods. Pork leg meat (71.18% moisture, 20.47% protein, 7.14% fat) and backfat (8.30% moisture, 1.68% protein and 89.82% fat, AOAC, 2000) were purchased from a local meat market (24 to 48 h postmortem, muscle pH 5.78). All visible connective tissue was trimmed from the meat. The lean meat and backfat were separately mixed and passed through a grinder (MM-12, Guangdong, China) fitted with a plate having 6 mm diameter holes. The ground meat (1.0 kg each) was packaged in double plastic (nylon/PE) bags and stored at −20 °C until use, within 2 weeks. The base ingredients consisted of the pork leg meat (1000 g) and back fat (250 g), with
2.2. Color measurement

For the color measurement, the thawed ground meat was processed using a beating machine (MC-6, Shandong, China) as follows: the thawed ground meat was beaten with salt (NaCl) and sodium tripolyphosphate for 10 min (200 rpm); followed by addition of the sugar, pepper and pork backfat and mixed (200 rpm) to a batter for 5 min (final temperature less than 10 °C). The processing conditions used were equivalent to those of a commercial operation. For the chopping method, the products were prepared using a typical emulsification procedure in a vacuum cutter bowl (Stephan UMC-5C, Germany) as described by Lin and Lin (2004) with slight modification. The thawed ground meat was chopped (1500 rpm) with salt and sodium tripolyphosphate for 30 s, followed by a 3 min rest and then the sugar, pepper and pork backfat were added and chopped (1500 rpm) for 30 s, followed by a 3 min rest, prior to finishing with a high speed (3000 rpm) emulsification for 60 s (final temperature less than 10 °C). Then the prepared meat batter was shaped into meatballs of 30 mm diameter, cooked in 80 °C water for 20 min, cooled to room temperature. The texture properties of the meatballs were determined using a texture analyzer (TA-XT. plus, Stable Micro system Ltd., Surrey, UK) fitted with a cylindrical probe (P/50, 50 mm stainless cylinder). The conditions were as follows: pre-text speed 2.0 mm/s; post-text speed 5.0 mm/s; strain 50%; time 5.0 s; trigger type, auto; and trigger force 5 g for TPA measurement. The meatballs were cut in two to give 20 mm deep and 25 mm diameter strips. A mean of five measurements was obtained for each texture profile analysis. The following parameters were determined: hardness, springiness, cohesiveness, chewiness, and gumminess (Bourne, 1978).

2.3. Salt-soluble proteins

Salt-soluble proteins were determined using a modified procedure of Cofrades, Serrano, Ayo, Carballo, and Jimenez-Colmenero (2008). Ten grams of each sample was homogenized in a polytron homogenizer (T25 digital, IKA Ltd., Germany) at 15,000 rpm for 90 s at 2–4 °C in 50 mL phosphate solution (0.6 M NaCl and 20 mM phosphate, pH 7.0). The raw batter was centrifuged (Beckman L-80-XP Ultra-centrifuge, USA) for 30 min at 27,200 g and 4 °C, and the protein content in the supernatant of each sample was determined according to Lowry, Rosebrough, Farr, and Randall (1951), using bovine serum albumin as a standard. The results were expressed as the percentage of protein solubilized with respect to the total protein content of the meat batter (AOAC, 2000).

2.4. Cooking yield

Cooking yields were measured by the weight difference before and after the final cooking (Hsu & Chung, 1998).

2.5. Texture profile analysis (TPA)

Frozen meatballs were thawed at 2 °C for approximately 12 h. Once thawed, they were heated at 80 °C in a water bath for 15 min and then cooled to room temperature. The texture profile analysis (TPA) attributes of the meatballs were determined using a texture analyzer (TA-XT plus, Stable Micro system Ltd., Surrey, UK) fitted with a cylindrical probe (P/50, 50 mm stainless cylinder). The conditions were as follows: pre-text speed 2.0 mm/s; post-text speed 5.0 mm/s; strain 50%; time 5.0 s; trigger type, auto; and trigger force 5 g for TPA measurement. The meatballs were cut in two to give 20 mm deep and 25 mm diameter strips. A mean of five measurements was obtained for each texture profile analysis. The following parameters were determined: hardness, springiness, cohesiveness, chewiness, and gumminess (Bourne, 1978).

2.6. Raman spectroscopy

Raman experiments were determined using a modified procedure of Shao, Zou, Xu, Wu, and Zhou (2011). Spectra were smoothed, baselines corrected and normalized against the phenylalanine band at 1003 cm−1 (Herrero, 2008; Li-Chan, Nakai, & Hirostuka, 1994) using Labspec version 3.01c (Horiba/Jobin, Yvon, Longjumeau, France). The secondary structures of the raw meat batter proteins were determined as percentages of α-helix, β-sheet, β-turn, and random coil or unordered conformations (Alix, Pedanou, & Berjot, 1988). With this aim, the water spectrum was subtracted from the spectra by following the same criteria.

Table 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>Raw batter</th>
<th>Kung-wan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*-value</td>
<td>a*-value</td>
</tr>
<tr>
<td>C1</td>
<td>65.87 ± 0.98d</td>
<td>13.73 ± 0.88a</td>
</tr>
<tr>
<td>C2</td>
<td>66.31 ± 1.56d</td>
<td>12.12 ± 0.40b</td>
</tr>
<tr>
<td>C3</td>
<td>66.69 ± 1.01d</td>
<td>10.71 ± 0.54a</td>
</tr>
<tr>
<td>C4</td>
<td>68.25 ± 1.12d</td>
<td>10.07 ± 0.60a</td>
</tr>
<tr>
<td>T1</td>
<td>66.81 ± 0.94d</td>
<td>12.33 ± 0.76b</td>
</tr>
<tr>
<td>T2</td>
<td>69.18 ± 0.69d</td>
<td>10.94 ± 0.59a</td>
</tr>
<tr>
<td>T3</td>
<td>68.70 ± 1.75d</td>
<td>10.57 ± 0.16a</td>
</tr>
<tr>
<td>T4</td>
<td>70.48 ± 0.92d</td>
<td>10.08 ± 0.74d</td>
</tr>
</tbody>
</table>

*Different parameter superscripts in the same column indicate significant differences (p < 0.05).

C1: chopping with 0.5% NaCl; C2: 1% NaCl; C3: 2% NaCl; C4: 3% NaCl; T1: beating with 0.5% NaCl; T2: 1% NaCl; T3: 2% NaCl; T4: 3% NaCl.
as described previously (Alix et al., 1988; Herrero, Carmona, Pintado, Jimenez-Colmenero, & Ruiz-Capillas, 2011).

2.7. Scanning electron microscopy

The microstructure was determined using scanning electron microscopy (Hitachi-S-3000N, Hitachi High Technologies Corp., Tokyo, Japan), essentially as described by Haga and Ohashi (1984). Cubic samples (3 × 3 × 3 mm\(^3\)) obtained from raw meat batters and kung-wans were fixed for 24 h at 4 °C in a 0.1 M phosphate buffer (pH 7.0) containing 2.5% glutaraldehyde. The fixed samples were washed in 0.1 M phosphate buffer (pH 7.0) for 10 min, and then post-fixed for 5 h in the same buffer with 1% osmium tetroxide. The post-fixed samples were washed three times with 0.1 M phosphate buffer (pH 7.0) for 10 min and dehydrated in incremental concentrations of ethanol (50, 60, 70, 80, 90, and 95%, and three times with 100%) for 10 min for each solution.

2.8. Statistical analysis

The experiment was designed as a complete randomized block with four replications and twenty samples were used for each replicate. The data was analyzed using the one-way ANOVA program. The differences between means was considered significant if \( p < 0.05 \). Significant differences between means were identified by the LSD procedure using the statistical software package SPSS v.18.0 for windows.

3. Results and discussion

3.1. Instrumental color

The color of the raw batters and kung-wans, formulated with various salt contents, prepared by either the chopping or beating process is presented in Table 1. The \( L^\star \) values of raw batters and kung-wans increased with increasing salt contents in both the chopping and beating treatments, whereas the \( a^\star \) values decreased in each case. Tobin, O’Sullivan, Hamill, and Kerry (2012) found that frankfurters containing 1.5% and 1% salt had darker/deeper colors than those made with higher salt contents (2%, 2.5% and 3%). At the same salt content, the products’ color was significantly affected (\( p < 0.05 \)) by the process. Beating caused the products to have higher \( L^\star \) values than those produced by chopping, and to have lower \( a^\star \) and \( b^\star \) values. T4 had the highest \( L^\star \) values, and the lowest \( a^\star \) values. Sample T2 had similar \( L^\star \) values to C4 and T3, and higher than C2 and C3. The color of emulsified meat products is influenced by the meat pigments and structural proteins and the extent of their denaturation (Grossi, Soltotf-Jensen, Knudsen, Christensen, & Orlien, 2012). It is also affected by protein–fat interactions and the homogeneity of the cut surface of the product (Alvarez et al., 2007; Grossi, Soltotf-Jensen, Knudsen, Christensen, & Orlien, 2011). Tobin et al. (2012) reported that when the myoglobin content was kept constant, the color of frankfurters was mostly influenced by the fat content, added water and processing conditions. Samples C2 and T2 were prepared by different processing methods. Since the beating treatment had been applied for a longer period, there may have been more local denaturation and myoglobin oxidation, resulting in greater discoloration in the beaten product (Carlez, Veciana-Nogues, & Cheftel, 1995).

3.2. Salt soluble protein

Fig. 2 shows the concentrations of salt-soluble proteins (SSP) for each of the meat batters. All samples showed a significant increase (\( p < 0.05 \)) in SSP with increasing salt contents. Preparations C4 and T4 had the highest SSP concentration in each treatment. When the salt content was reduced, the amount of extracted SSP decreased (Gordon & Barbut, 1992a). Salt is necessary during meat processing as it causes swelling of myofibrillar proteins, depolymerizes myofilaments and dissociates the actomyosin complex (Xiong, 1997). Totosaus and Perez-Chabela (2009) reported that reduced salt concentrations lead to decreases in the amounts of extracted and solubilized myofibrillar proteins in pork and beef batters. At the same salt level, the different mechanical processes used had a significant (\( p < 0.05 \)) effect on the SSP concentrations. Those samples subjected to the beating process had higher SSP concentrations compared with those prepared by chopping, with T4 having the highest SSP concentrations among the samples. The SSP concentration of T2 was higher than C2 and C3, but similar to T3 and C4. In both the chopping and beating methods the connective tissue fibers are largely disrupted and the myofibrillar structures broken, but there appears to be a difference in the resulting homogenate. The bowl cutter has been described as a continuously stirred tank reactor (Vodyanova, Storr, Olsen, & Rustad, 2012) and within this complex process, the particle size of the raw material is reduced, being dependent on the speed of the sharp knives (\( > 1500 \text{ rpm} \)). The beating machine disrupts connective tissue and myofibrillar structures dependent on the speed of the blunt blades (200 rpm), but does so with a crushing force on the meat. The blunt blades rotate with meat at different speeds, thus enhancing the frictional forces and exchange of soluble components in the processed meats. The beating method is conducive to SSP dissolution during processing, and inducing protein structural changes through electrostatic interactions between muscle proteins and the sodium and chloride ions (Xiong, 1997).

3.3. Cooking yield

Both the homogenization process and salt content had significant effects (\( p < 0.05 \)) on cooking yields except for C4, T2 and T3 (Fig. 3). Sample T4 had significantly higher cooking yields than the other treatments. However, C4, T2 and T3 had similar cooking yields, which were higher than C2 and C3, as these treatments had higher salt contents and higher SSP concentrations. Lan et al. (1995) indicated that protein concentration had significant effects on cooking yield. Hsu and Chung (1998, 1999) showed that the more salt-soluble protein extracted from the meat allowed formation of more stable meat emulsions, which resulted in higher cooking yields. The beating process increases SSP concentration, and forms a better protein matrix utilizing more SSP and insoluble materials. A similar result was reported by Sikes et al. (2009) who showed that when high pressure was applied to meat emulsions there was an

![Fig. 2. Percentage of salt-soluble proteins (SSP) of raw batters when produced by chopping (C) or beating (T) with various amounts of added salts; C1, T1: 0.5% NaCl; C2, T2: 1% NaCl; C3, T3: 2% NaCl; C4, T4: 3% NaCl. Each value represents the mean ± SD, \( n = 4 \). *Different parameter superscripts in the figure indicate significant differences (\( p < 0.05 \)).](image-url)
increase in the solubility of muscle proteins and hence an improvement in the functional characteristics of the myofibrillar proteins.

3.4. Texture profile analysis

Texture profile analysis parameters were affected by the processing method (Table 2). Increasing salt levels significantly increased (p < 0.05) the hardness, springiness, cohesiveness, gumminess and chewiness of the chopped samples. Sample C4 had the best texture among the treatments. Myofibrillar protein (MP) plays an essential role in producing the desirable texture in comminuted meat products. Pietrasik and Li-Chan (2002) reported that different ratios of salt soluble proteins may have been involved in network formation at the different salt levels. Reduced salt levels lead to a decrease in extracted and solubilized myofibrillar proteins such as myosin and actin, thus affecting the functionality of the kung-wan prepared with the cutter bowl. In the beaten samples, texture improved with increasing salt levels. However, T2 and T3 had higher SSP concentrations, which further enhanced on the protein content, particularly in C4. Similar results were reported by Perisic, Afseth, Ofstad, Hassani, and Kohler (2013) who showed that increased salt concentration caused an increase in the amount of β-sheets. However with beating, all batters had similar β-sheet contents (p > 0.05). The results indicated that the effects on the β-sheet contents of the structures were affected more by the beating process than by the salt concentration.

Again, the processing method had a significant effect (p < 0.05) on α-helix, β-sheet, β-turn and unordered contents. The α-helix content of the beaten batters was less than those prepared by chopping and had higher β-sheet, β-turn and unordered contents, implying α-helical structures are transformed into β-sheets (Boecker et al., 2007). Liu, Zhao, Xiong, Xie, and Qin (2008) reported that the unfolding of α-helix and the formation of β-sheets favored the gelation of porcine myosin. Herrero (2008) and Liu et al. (2010) had a higher SSP concentration than any of the chopped samples, except for C4. Increasing the protein level generated more rigid structures resulting in higher hardness, chewiness, and gumminess values (Youssef & Barbut, 2011). Samples T2 and T3 had better gel textures on the basis of protein matrix and interfacial protein films (Gordon & Barbut, 1992b; Hermansson, Harbitz, & Langton, 1986). During processing, the beating process may form a better protein matrix than the chopping one.

Table 3

Percentages of protein secondary structures α-helix, β-sheet, β-turns, and unordered of the raw meat batters analyzed by chopping or beating process with various amounts of added salt.

<table>
<thead>
<tr>
<th>Sample</th>
<th>α-Helix (%)</th>
<th>β-Sheet (%)</th>
<th>β-Turns (%)</th>
<th>Unordered (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>77.34 ± 3.26a</td>
<td>2.51 ± 2.50d</td>
<td>11.73 ± 0.51e</td>
<td>8.92 ± 0.20f</td>
</tr>
<tr>
<td>C2</td>
<td>69.84 ± 3.24a</td>
<td>8.26 ± 2.48b</td>
<td>12.91 ± 0.51b</td>
<td>9.38 ± 0.20b</td>
</tr>
<tr>
<td>C3</td>
<td>75.47 ± 1.08a</td>
<td>3.94 ± 0.49a</td>
<td>12.02 ± 0.12e</td>
<td>9.03 ± 0.40a</td>
</tr>
<tr>
<td>C4</td>
<td>68.59 ± 6.50b</td>
<td>9.21 ± 0.83b</td>
<td>13.10 ± 0.17ab</td>
<td>9.45 ± 0.07b</td>
</tr>
<tr>
<td>T1</td>
<td>64.21 ± 6.50b</td>
<td>12.57 ± 4.98a</td>
<td>13.79 ± 1.02a</td>
<td>9.72 ± 0.40a</td>
</tr>
<tr>
<td>T2</td>
<td>62.35 ± 0.00c</td>
<td>13.99 ± 0.00a</td>
<td>14.08 ± 0.00a</td>
<td>9.84 ± 0.00a</td>
</tr>
<tr>
<td>T3</td>
<td>66.08 ± 8.59b</td>
<td>11.13 ± 6.58ab</td>
<td>13.49 ± 1.35a</td>
<td>9.61 ± 0.52ab</td>
</tr>
<tr>
<td>T4</td>
<td>59.50 ± 5.72a</td>
<td>16.18 ± 4.39a</td>
<td>14.53 ± 0.90b</td>
<td>10.01 ± 0.35a</td>
</tr>
</tbody>
</table>

*p* Different parameter superscripts in the same column indicate significant differences (p < 0.05).

3.5. Raman spectroscopic analysis

The secondary structures of the raw meat batters were affected by salt content and processing method (Table 3). With the same processing method, there were no significant effects (p > 0.05) of salt content on the α-helical content although there was a tendency for it to decline. With chopped batters, there was a significant increase (p < 0.05) in the content of β-sheet structures with increasing salt content, particularly in C4. Similar results were reported by Perisic, Afseth, Ofstad, Hassani, and Kohler (2013) who showed that increased salt concentration caused an increase in the amount of β-sheet structures. However with beating, all batters had similar β-sheet contents (p > 0.05). The results indicated that the effects on the β-sheet contents of the structures were affected more by the beating process than by the salt concentration.

In the beating process, the beating process had a significant effect (p < 0.05) on α-helix, β-sheet, β-turn and unordered contents. The α-helix content of the beaten batters was less than those prepared by chopping and had higher β-sheet, β-turn and unordered contents, implying α-helical structures are transformed into β-sheets (Boecker et al., 2007). Liu, Zhao, Xiong, Xie, and Qin (2008) reported that the unfolding of α-helix and the formation of β-sheets favored the gelation of porcine myosin. Herrero (2008) and Liu et al. (2010) had higher SSP concentration than any of the chopped samples, except for C4.
shown that in meat systems, increases in the proportions of β-sheet and β-turn structures were accompanied by increases in hardness, springiness and cohesiveness. This is due to the buried residues in the protein molecule (such as hydrophobic amino acid residues tyrosine and phenylalanine) becoming more exposed to the water molecules when the protein is subjected to the beating process.

3.6. Microstructure

Micrographs of cooked kung-wans showed that the different salt contents (1% and 2%) and the process affected some properties of the emulsion structure (Fig. 4). With the chopped product at low salt concentration (C2) the emulsion had a lower SSP concentration and the matrix generally became disorganized and lost much of its honeycomb-like appearance. However, at higher salt content (C3), the kung-wan showed a spongy appearance with numerous cavities and was characteristic of a cooked meat emulsion (Carballo, Fernandez, Barreto, Solas, & Jimenez-Colmenero, 1996; Delgado-Pando et al., 2011). Unlike the chopped product, the kung-wan prepared by beating had a uniform network at low (T2) and high (T3) salt contents. Micrographs of T2 and T3 showed a spongy structure, with more uniform cavity formation, that was clearly morphologically different (generally smaller) from the C3. These morphological differences were attributed to the beating process giving different characteristics to the batters and kung-wans, such as SSP concentration and texture. Therefore increased SSP concentrations in the meat matrix improve the water-holding capacity and produce a product of improved texture.

4. Conclusions

The use of different salt contents and processing methods significantly influenced the properties of both the raw batters and cooked kung-wans. Improved color (L* value), cooking yield, protein solubility and texture were obtained with increasing salt content. At the same salt content, the raw meat batters and cooked kung-wans produced by beating, had better quality characteristics (enhanced L* values, protein solubility and texture, and improved cooking yield) compared with those prepared by chopping. From the micrographs, T2 and T3 had a smoother and more uniform microstructure than either C2 or C3. The likely reason is that the beating process brought about changes in the secondary structures of the myofibrillar proteins in the presence of 1% and 2% salt. The results showed that by using the beating process it was possible to produce low salt kung-wans having the desired textural qualities of high hardness, brittleness and elasticity.

Acknowledgments

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